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What are the Key Indicators of Mega Sustainable Construction Projects? —A Stakeholder-Network Perspective

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Abstract: Mega sustainable construction projects (MSCPs) require complex system engineering. There are various indicators available to evaluate sustainable construction, and it is difficult to determine which the key indicators are among them. Existing studies do not adequately consider the stakeholders associated with the indicators of sustainable construction, leading to key decision-makers' lack of targeted management strategies to improve the sustainability level of MSCPs. Using literature analysis and expert interviews, this study identified the key evaluation indicators of MSCPs from a stakeholder-network perspective. Social network analysis (SNA) was used to explore the relationships between the key evaluation indicators and corresponding stakeholders. The results showed that the government and designers significantly impacted other stakeholders and played as the key stakeholders in MSCPs. Regarding the indicators, applying energy-saving and intelligent technologies plays a key role in the MSCPs. This study links key indicators of MSCPs with the associated stakeholders, which helps decision-makers to develop targeted strategies to improve the sustainability level of MSCPs, thereby not only improving the efficiency and effectiveness of the intervention strategies, but also helping to save decision-makers' monetary and human resources which are usually limited.

Keywords: MSCPs; stakeholders; evaluation indicator; social network analysis

1. Introduction

The increasing fixed asset investments led to China's rapidly developing construction industry. This development generated a significant amount of energy consumption, waste, and greenhouse gas emissions. Energy consumption accounts for two-thirds of global greenhouse gas emissions [1]. This highlights the need for the construction industry to reduce greenhouse gas emissions and the negative impacts on the environment. Sustainable construction can be defined as "building a healthy environment based on resource efficiency and ecological principles" [2]. Mega sustainable construction projects (MSCPs) are extremely large-scale projects typically costing more than $1 billion such as power-plant highways and tunnels, bridges, railways, seaports, and enormous projects for cultural events [3]. Many domains are involved in these mega projects, which leads to the inherent complexity of technology, structure, society, and management associated with megaprojects. MSCPs must integrate sustainability objectives (i.e., aspects related to the environment, economy, and society) with three project management objectives (duration, quality, and cost) [4]. Managers and decision-makers who lead MSCPs must consider, balance, and incorporate environmental, economic, and social indicators into the criteria for evaluating megaprojects [5].

Previous research on the evaluation indicators for assessing the sustainability level of construction projects focused on the characteristics of evaluation indicators, such as determining the weights of the indicators and on comparing different evaluation systems [6,7]. Studies also developed recommendations through simulation and modeling [8–10]. However, most existing studies paid little attention to the stakeholders influenced by or responsible for the implementation of the indicators. MSCPs involve a wide range of stakeholders, who have their own interests and are interested in various types of objectives. MSCPs are a complex adaptive system that requires close collaboration among different stakeholders to achieve the sustainability objectives of the project [11]. Fully considering the interests of all parties can continuously and effectively improve the project's sustainability level. Therefore, MSCPs should be closely linked with stakeholders to set the objectives [12].

As a network analysis tool, social network analysis (SNA) emphasizes the inclusion of social science variables in complex project management. It considers the complexities brought by stakeholder relationships and their chain effects on the project. SNA is appropriate for analyzing the network of mega construction projects, and for other projects involving many objects and interdependent, iterative, and interactive relationships [13]. Using SNA to assess the interrelationships among stakeholders can contribute to achieving the sustainability objectives of projects. Therefore, this study adopted the SNA method to establish relationships between stakeholders and indicators for MSCPs based on the dimensions of society, economy, and environment. This study had the following objectives:

I. To use literature analysis and interviews to identify the key indicators for evaluating MSCPs.
II. To use workshops to establish links between different evaluation indicators and the corresponding stakeholders.
III. To use the SNA method to construct a network of the evaluation indicators and identify the key stakeholders and indicators in the network.

Few studies aimed to identify the critical evaluation indicators of sustainable construction considering stakeholders who are influenced by the indicators [14]. In this study, a stakeholder-indicator network model based on SNA was constructed, expanding the body of knowledge relating to sustainable construction. The identified key stakeholders and indicators could be used by relevant decision-makers to develop targeted strategies to improve the sustainability performance of mega construction projects.

2. Literature Review

Sustainable development means such a development that satisfies the present needs without a limitation of the possibility of satisfying the needs in the future [15]. Many composite indicators are used to measure the sustainable development of construction projects. These indicators should take into account the triple bottom line approach of sustainability, and therefore, include economic, environmental, and social dimensions in their assessment [16]. Accordingly, it is important for MSCPs to achieve a balance amongst the environmental, economic and social objectives. Kibwami and Tuteigensii [17] indicated that sustainable construction has three sets of goals, namely the economic, social, and environmental goals. In addition, there are previous studies on the indicators for evaluating MSCPs. For instance, Fernández-Sánchez and Rodríguez-López [18] used a sustainable breakdown structure (SBS) to reduce subjectivity and uncertainty in the process of indicator selection, and they divided the sustainability indicators into social, environmental, and economic dimensions as well. This is further supported by Zhong and Wu [19], who also built a sustainability evaluation system from the same three dimensions, as well as Whang and Kim [20], who highlighted the need to balance these dimensions in successfully achieving sustainability. Based on these previous studies, this research centered on the three dimensions of society, economy, and environment. This study synthesized previous studies and accounted for the linkages between stakeholders and the evaluation indicators for MSCPs.

2.1. Stakeholders in MSCPs

Stakeholder refers to "any group or individual that is likely to be affected or affecting the achievement of organizational goals" [21]. The Project Management Institute (PMI) Standards Committee defines project stakeholders as individuals and organizations who are active in the project, or those whose interests may be affected by project implementation or successful completion of the project. Compared with traditional construction projects, mega sustainable construction projects emphasized more types of stakeholders such as the public, suppliers, financial institutions, end-users, and professional associations. Many different types of stakeholders in mega projects have more uncertainties than traditional projects when they are faced with risks. Based on extensive literature analysis and semi-structured interviews, Yang and Shen [22] grouped construction project stakeholders into 14 categories, including clients, contractors, consultants, suppliers, end-users, governments, financiers/sponsors, communities, district councils, the general public, competitors, utilities, special interest groups, and the media. Similarly, Yang and Zou [23] grouped construction project stakeholders as clients, consultants, contractors, subcontractors/suppliers, end-users, financial organizations, government, environmental protection organizations, professional associations, media, the public, trade unions, evaluators/certifiers, and researchers/educators. Davis [24] proposed stakeholders of MSCPs should include the government, financiers, developers, consultants, suppliers, designers, owners, supervisors, contractors, sub-contractors, and end-users. Mok et al. [25] argued construction project stakeholders should include clients, consultants, the main contractor, engineers, subcontractors, end-users, and others.

Often initiated by the government, mega construction projects usually require massive investments in infrastructure, which have a long schedule, long lifespan, extreme complexity, and significant social impacts [26]. Mega construction projects are usually very complex in nature and each megaproject could easily cost over $1 billion [27]. MSCPs are a complex concept involving both the primary and secondary stakeholders [28,29]. Clients, owners, contractors, designers, suppliers, and governments have a direct link to mega construction projects. They often have sufficient influence on sustainable construction, and thus, could be considered as primary stakeholders [30]. Secondary stakeholders mainly refer to assessment organizations, scientific research institutions, and the surrounding people who do not directly participate in the project construction process.

Stakeholders have different interests in the development process of MSCPs. If their expectations and interests are not met, conflicts among them could emerge which hinders project success [31,32]. Stakeholder theory indicates that, to achieve sustainable development, organizations must balance different stakeholder interests [22]. Managing multiple stakeholders and maintaining an acceptable balance between their interests is the key to project delivery success [33–35]. Effective stakeholder management requires highly reliable and effective information exchange, which could eliminate information asymmetry among stakeholders [36]. In addition, by strengthening the cooperative relationships between stakeholders, the net benefits of MSCPs can be improved, especially for the owners and contractors [37].

2.2. Evaluation Indicators for MSCPs

The implementation of sustainable projects requires effective stakeholder management at all project stages. Such projects also require an accounting of the project's social, economic, and environmental implications [38]. Life-cycle assessment (LCA) is the most widely used method to assess the environmental impact of construction projects, including mega projects. LCA is particularly useful for quantifying CO_2 emissions, renewable energy use, water consumption, and other environmental factors in mega construction projects [39]. Past studies also compared different evaluation systems for green buildings, such as LEED (Leadership in Energy and

Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), CASBEE (Comprehensive Assessment System for Built Environment Efficiency), BEAM (Building Environmental Assessment Method), and SB Tool (Sustainable Building Tool) [40,41].

Previous studies also employed various methods to assess the sustainability performance of construction projects. Fernández-Sánchez and Rodríguez-López [18] proposed a framework of sustainability indicators assessing infrastructure projects. Aboushady and El-Sawy [42] used the analytical hierarchy process (AHP) method to develop the sustainability indicators of mega infrastructure construction projects. Waas et al. [43] used sustainability assessment (SA) and sustainability indicators (SIs) as theoretical tools for evaluating the decision strategies of sustainable construction. Chen et al. [10] combined fuzzy set theory, the Delphi method, and the discrete multi-criteria method, to analyze the sustainable development indicators in the uncertain economic environment. Lin et al. [14] used a structured method and a quantitative analysis model to develop an indicator system to evaluate megaproject social responsibility effectively.

Most of these evaluation methods and tools focus on project impacts on the environment and energy efficiency, without a holistic perspective on sustainability including the economic, financial, and social aspects [44]. This gap slowed down the development of assessment indicators for MSCPs [45]. Sustainable construction performance needs to be assessed by a combination of indicators, including energy consumption, thermal comfort levels, resident well-being, and productivity [46]. These indicators should respond to various stakeholders' sustainability interests as well. However, few existing studies aim to link the assessment indicators with the associated stakeholders. As mentioned in Section 2.1, MSCPs typically involve various stakeholder groups with complex interests and interactions. Accordingly, linking indicator analysis and stakeholder management can effectively achieve sustainable development in MSCPs. Therefore, identifying critical indicators based on a perspective of stakeholders is a critical concern. This study aims to bridge these research gaps.

3. Methodology

3.1. Research Instrument Development

The research process for this study was designed in four stages (Figure 1). Based on the two methods of identifying stakeholders (empiricism and rationalism) proposed by Yang [47], Mok et al. [25] combined the two methods to analyze the stakeholders comprehensively. This study identified 12 types of stakeholders for MSCPs through literature analysis, including governments (S1), owners/investors (S2), planning/design enterprises (S3), contractors (S4), subcontractors/suppliers (S5), financial institutions (S6), environmental protection organizations (S7), evaluators/certifiers (S8), scientific/educational institutions (S9), end-users (S10), professional associations (S11), and surrounding populations (S12). The list of 12 stakeholders was then presented to 13 experts in the pilot study (Table 1) in the field of sustainable construction for further comments. With rich experience and knowledge for MSCPs, all interviewees were selected following a stakeholder-based sampling principle to ensure the data were representative.

To identify the evaluation indicators for MSCPs, 28 evaluation indicators were obtained from a literature analysis. The indicator list was further revised according to 13 experts' feedback. Eventually, 23 evaluation indicators were identified as shown in Table 2. Five evaluation indicators were deleted because they were duplicated with other indicators. A relationship table was developed to link sustainable construction evaluation indicators with the stakeholders (Table 2). The design structural matrix method was adopted in this study to define the links in the evaluation indicator network. The link was defined by the impact from one indicator to the other. The data were collected from workshops and interviews, with more details in the following sections. The initial data collection process lasted two months. After the data were collected and collated, the results were reported back to the interviewees, to facilitate the identification of fuzzy areas.

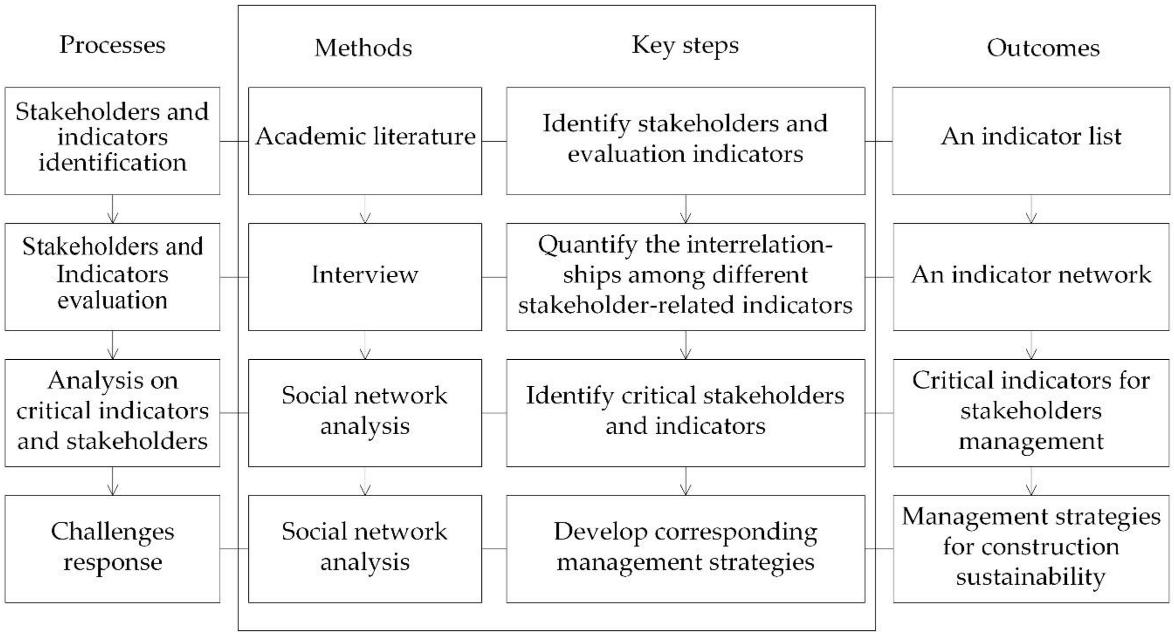

Figure 1. Research framework.

Table 1. Background of experts in the face-to-face interviews. MSCPs—mega sustainable construction projects.

Organization	Role of Interviewee	Ages	Experience in Construction	Number of MSCPs Involved in
Construction company	Senior engineer	36	10 years	4
Construction company	Civil engineer	38	12 years	5
Construction company	Project manager A	56	24 years	10
Construction company	Project manager B	53	23 years	10
House builder	Developer A	45	17 years	8
House builder	Developer B	44	15 years	7
House builder	Design engineer	55	32 years	12
Research institutions	Professor A	56	25 years	9
Research institutions	Professor B	54	24 years	8
Construction and technical services organization	Consultant A	41	17 years	14
Construction and technical services organization	Consultant B	38	14 years	12
Real estate firm	Architectural	48	17 years	8
Real estate firm	Architectural	45	15 years	7

Table 2. Project stakeholder-associated indicators.

Index	Index Name	Stakeholder	Index ID	Source	Dimension
N1	Recycling of materials and water	S3 S4 S5	S3N1 S4N1 S5N1	[48,49]	Environment
N2	Land use	S1 S2 S3	S1N2 S2N2 S3N2	[48–50]	
N3	Material resources	S3 S4 S5	S3N3 S4N3 S5N3	[48,49]	
N4	Waste management	S1 S4 S5	S1N4 S4N4 S5N4	[40,42,49,51]	
N5	Ecosystem	S3 S4 S5	S3N5 S4N5 S5N5	[40,50,52]	

Table 2. *Cont.*

Index	Index Name	Stakeholder	Index ID	Source	Dimension
N6	Protection of water resources	S1 S3 S4 S5 S7	S1N6 S3N6 S4N6 S5N6 S7N6	[48,53]	
N7	Air quality around the project	S4 S5	S4N7 S5N7	[40,49]	
N8	Indoor environmental quality	S2 S3 S10	S2N8 S3N8 S10N8	[54–56]	
N9	Greenhouse gas emissions	S1 S3 S4 S5	S1N9 S3N9 S4N9 S5N9	[18,49,57]	
N10	Noise level	S1 S4 S5 S12	S1N10 S4N10 S5N10 S12N10	[42,49,58]	
N11	Renewable energy efficiency	S3 S7 S8	S3N10 S7N10 S8N10	[42,49,57,59]	
N12	Best energy performance	S3 S11	S3N12 S11N12	[60]	
N13	Application of energy saving, ecology, and intelligent technology	S3 S7 S9	S3N13 S7N13 S9N13	[8,53]	
N14	Cost-effectiveness	S2 S3 S4 S6	S2N14 S3N14 S4N14 S6N14	[8,18,40,42,53,61]	Economy
N15	Percentage of population receiving external benefits in project-affected areas	S7 S9 S12	S7N15 S9N15 S12N15	[55,62]	
N16	Economic diversity in project-affected areas	S1 S2 S6	S1N16 S2N16 S6N16	[58,62]	
N17	Life/endurance of construction and design	S3 S4 S5	S3N17 S4N17 S5N17	[53]	
N18	Maintenance and renovation	S3 S4 S5	S3N18 S4N18 S5N18	[53]	
N19	Market supply and demand	S1 S2 S12	S1N19 S2N19 S12N19	[49,54,55,58]	Society
N20	Percentage of community residents who must be relocated due to the project	S1 S12	S1N20 S12N20	[49,54,55,58]	
N21	Work created throughout the project cycle	S4 S5 S12	S4N21 S5N21 S12N21	[56,58,63]	
N22	Occupational health and safety	S3 S4 S5 S12	S3N22 S4N22 S5N22 S12N22	[42,55,56]	
N23	User and owner satisfaction	S2 S3 S4 S5 S10	S2N23 S3N23 S4N23 S5N23 S10N23	[56]	

3.2. Data Collection

Twelve types of stakeholders were contacted and invited to participate in this study. This study used snowball sampling technology to encourage more potential respondents to participate in the study [32]. A total of 120 potential interviewees were invited, and 36 were willing to participate in the interview, which leads to a response rate of 30%. Each type of stakeholder consisted of three individuals. Interviewees had 5–20 years of working experience, mainly in government departments, scientific research institutions, planning/design enterprises, and construction companies. These interviewees formed a workshop, which reduced ambiguity through open discussion and improved data reliability by sharing information among different participants [64,65]. In the workshop, 36 interviewees were divided into 12 different types of stakeholder groups. These groups were organized to identify stakeholder-associated indicators in the project. They then were asked to evaluate the tightness between different indicators and stakeholders. To ensure the reliability of the results, interview questions were sent to the interviewees via e-mail before the face-to-face workshop to prepare them for the event [32].

Roundtables started with an introduction of researchers. They discussed the objectives of this study and provided a list of topics to guide discussion. In the workshop, participants were asked to answer some types of "how" and "what" questions, such as how indicators are connected to stakeholders and what the degree is between different stakeholder-associated indicators. The workshop participants contributed to the development of a stakeholder-associated indicator interrelationship matrix in which the possibility and consequence of the impact between risks were determined with five-point values. A Likert scale (1 to express complete disagreement, and 5 to express complete consent) was used as well for some questions. This approach was similar to studies conducted by Li et al. [66]. To reduce ambiguity, we verbally explained questions that were not clear to the interviewees. After the workshop, the stakeholder-associated indicator interrelationship matrix was completed.

3.3. Data Analysis

To visualize the data, we established a structural matrix to determine the relationships between stakeholders and indicators. This step mainly defined the interactions between indicators. After transforming the data, the matrix data were entered into the NetMiner 4 software. This allowed the derivation of the network chart showing the sustainable construction evaluation indicator and the status centrality map.

In SNA, the first step is to identify the nodes. For this study, the number S_i (i = 1, 2–12) represents 12 stakeholders, and the number N_j (j = 1, 2–23) represents 23 evaluation indicators. For example, a line from S_1N_2 to S_3N_4 indicates that S_1N_2 affects S_3N_4. Then interviewees from S_1 and S_3 were interviewed to answer the question: "Can S_1N_2 affect S_3N_4, and if so, to what degree does S_1N_2 influence S_3N_4?" After collection, the data were entered into NetMiner 4 to visualize the network. According to the analysis of network characteristics in sustainable construction, this paper mainly analyzes the network density, network cohesion, node degree, intermediation, and status centrality of the stakeholder index network [25,65,67]. Table 3 explains the theoretical definitions of these SNA metrics. These indicators can reflect key nodes and key connections in the network, leading to key stakeholders and key evaluation indicators in the sustainable project network. Finally, effective measures were proposed for managing stakeholders in large sustainable construction projects.

Table 3. SNA metrics and their explanations.

Metrics	Theoretical Definition	Explanation
Density	The ratio of actual ties in a network to the greatest number of possible ties when all nodes are interconnected. [68].	Network density ranges between 0 and 1. The higher the density, the more indicator interrelations are there in the network.
Cohesion	The number of ties, or the length of path to reach nodes in a network [69]	The higher the cohesion, the closer the risks are connected in the network.

Table 3. *Cont.*

Metrics	Theoretical Definition	Explanation
In-degree	The number of direct incoming ties transmitted to a specific node [70].	A stakeholder with high in-degree has high accessibility to information in the project.
Out-degree	The number of direct outgoing ties emitted by a particular node [70].	A stakeholder with high out-degree is influential as it can quickly disseminate one's information to a large population.
Degree difference	The difference between out-degree and in-degree scores of a specific node [69].	A stakeholder with larger in-degree than out-degree is considered peripheral (i.e., less influential) in the project as it is an information receiver more than the provider.
Betweenness centrality	It calculates the occurrence in which a specific node/link is situated between other pairs of nodes/links on the basis of the shortest path [71].	This role facilitates communication by diffusing information to stakeholders who may otherwise be disintegrated from the network. This role may also interfere with communication if it transmits information in poor quality or untimely manner.

4. Results and Analysis

4.1. Identification of the Indicators for MSCPs

Based on the literature analysis and semi-structured interviews, this study identified 12 stakeholders and 23 evaluation indicators (Table 2) for MSCPs. The workshop participants identified 72 stakeholder-related indicators. There are 72 corresponding nodes in the figure, and 1495 links between the 72 nodes. These represent the interrelationships among the indicators. In addition, we calculated the out-degree and in-degree of each node to analyze node interactions. The out-degree is the effect of the node on other nodes, and the in-degree is the influence of other nodes on the node.

4.2. Network Analysis

In the sustainable construction network, each stakeholder-associated indicator was a network node. Node importance is determined by the degree of centrality, because the degree of centrality characterizes the ability of one node to develop interaction with other nodes. Figure 2 shows that the network nodes have 12 colors, representing 12 different stakeholders. The three shapes of the nodes represent the three dimensions of the indicators. A total of 1495 lines are connected to 72 nodes in this stakeholder-indicator network. The lines connecting the nodes represent information exchange relationships and node interactions. For example, pointing to S_aN_b from the node S_iN_j indicates that S_iN_j affects S_aN_b. The more connections a node has outside, the greater the node's impact. A few nodes have a very high density in the center. This means that these nodes play a central role throughout the network. Figure 2 shows that the network has more red, yellow, and green nodes than nodes of other colors. These indicate that most of the indicators were associated with these three stakeholders. The corresponding stakeholders are the government, planning/design enterprises, and the contractors, respectively. In addition, the evaluation indicators associated with these stakeholders also cover most of the network. This is another way of reflecting their importance.

The network density and cohesion were also calculated to quantitatively investigate the allocation of sustainable stakeholder indicator networks. The network density reflects the overall connectivity of the network, and the cohesion captures network complexity by considering the reachability of different nodes. The higher the network density is, the higher the degree of correlation between the indicators is. The greater the cohesion value is, the more complex the network is. In this study, the network density was 0.292, and the network cohesion value was 0.447. The value of network cohesion was higher than the network density. This indicates that when considering the propagation effect of the whole network, the interrelationships of the stakeholder indicator are more complex.

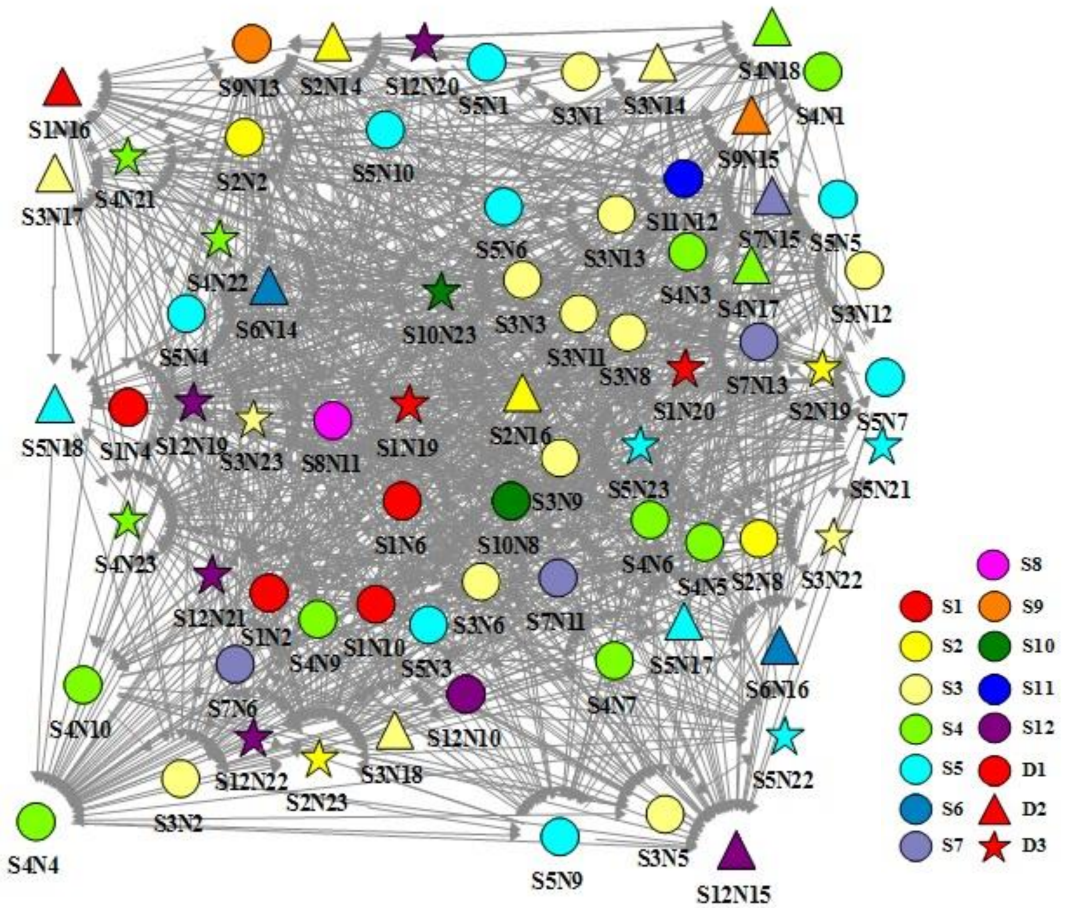

Figure 2. Stakeholder-associated sustainable index network.

4.3. Node and Link Level Analysis

Figure 3 shows the status centrality map of the stakeholder-indicator network. The node colors indicate the stakeholder groups, while the shapes show the indicator types. There are 10 concentric circles, reflecting the overall impact of each indicator. The closer the circle is to the center, the higher the degree of influence. The figure shows that the project's internal rate of return (N15) and user/owner satisfaction (N23) are at the center of the map. These placements indicate that these indicators have a high degree of impact on other indicators. In addition, subcontractors/suppliers, owners/investors, planning/design enterprises, and scientific/educational institutions associated with these high-impact indicators have a significant impact on other stakeholders in MSCPs.

When considering the full life cycle of mega construction projects, the first step is for investors to decide whether to invest in sustainable buildings, which require new technologies and new sets of skills compared to traditional projects. In this network, owners/investors are the stakeholders with the greatest impact on sustainable construction indicators, because they initiate the evaluation about whether to invest in MSCPs rather than in traditional mega construction projects. If investors invest in MSCPs, they must consider the requirements of different evaluation indicators throughout the project cycle. They should also sign contracts with contractors based on these requirements to ensure project sustainability. Scientific/educational institutions are secondary, because, under different cultural backgrounds and different evaluation angles, different local projects will be evaluated according to different types of mega construction projects, and the evaluation indicators differ. At this point, scientific research institutions need to research evaluation indicators and provide technical knowledge support to the government to determine indicators suitable for local projects. Finally, considering the significant social, economic, and environmental benefits created by MSCPs, the government formulates relevant policies according to research results in this area. This encourages investors to invest in MSCPs actively.

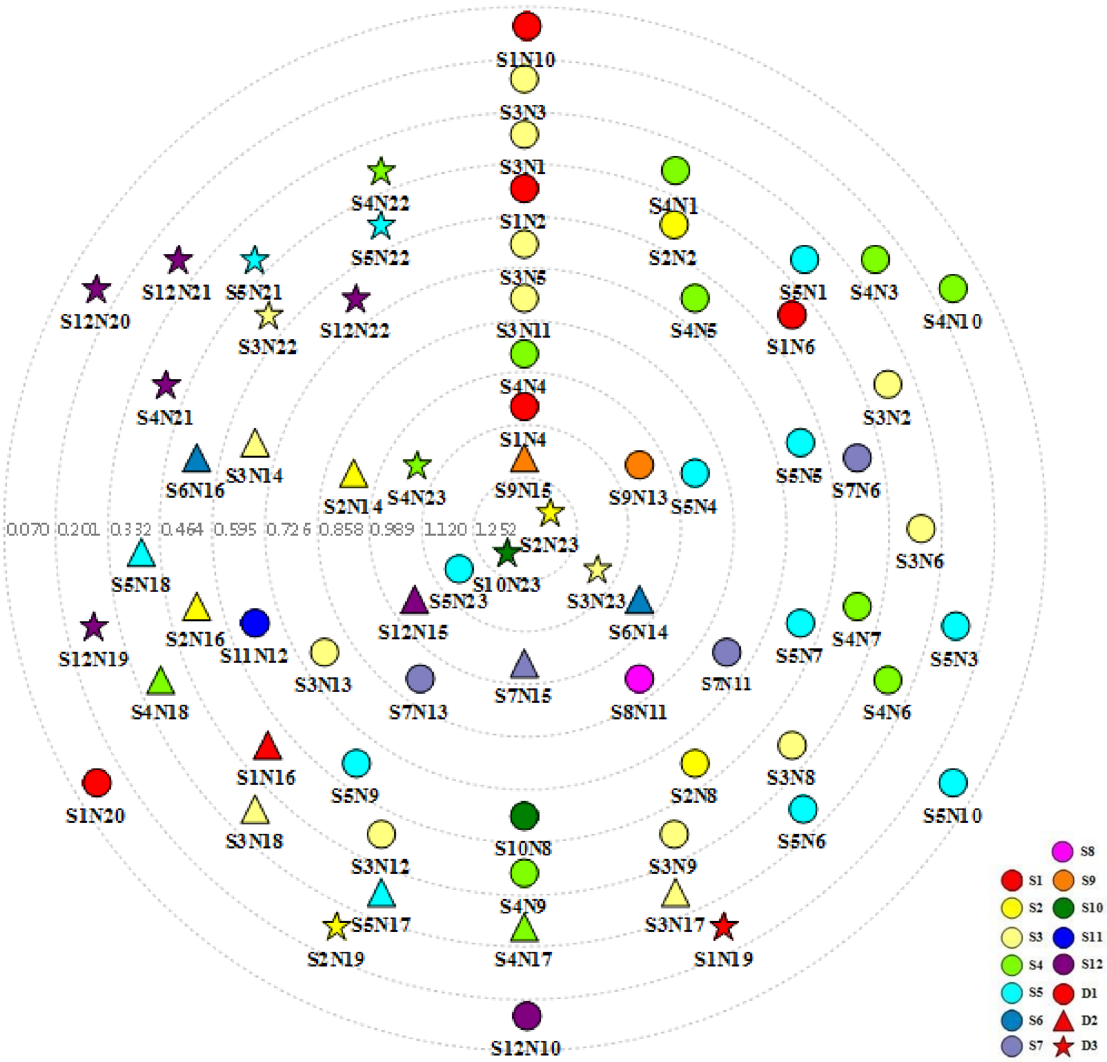

Figure 3. Indicator locations in the status centrality map.

In addition to the status centrality map, we calculated other node-level metrics, including self-network size, external centrality, out-degree, and degrees of difference (see Table 4). These values analyze the characteristics of evaluation indicators and their effects on the network of indicators from different perspectives. A large self-network scale indicates that many evaluation indicators are closely related to that node. Out-degree reflects the range of influence. The higher the out-degree is, the larger the range of influence is. In-degree is the number of lines to which the node as a target is incident. The degree of difference is equal to the difference between out-degree and in-degree [69]. The bigger the difference is, the greater the impact a specific node has on other nodes, compared to the impact of other nodes on itself [72]. Therefore, the index of these networks is calculated to see whether the index has more influence in the network. The index with a high value usually plays a more important role in the network of indicators. Table 4 shows that the waste management (S1N4) is an index near the top of the self-network scale index. Therefore, many indicators closely relate to the waste management. The highest out-degree values are seen with market supply and demand (S12N19), at a value of 141. This demonstrates that they have the largest range of influence on the evaluation indicator network. The difference in market supply and demand of MSCPs is the largest in the network indicator. This indicates that all indicators related to sustainable construction, such as the application of energy-saving technologies, waste management, and cost-effectiveness, are greatly affected by market supply and demand. These indicators themselves have little effect on market supply and demand.

Table 4. Ranking of critical indicators based on status centrality, ego network, and nodal degree analyses. ID—identifier.

Ranking	Index ID	Out-status Centrality	Index ID	Ego Size	Index ID	Out-degree	Index ID	Degree Difference
1	S12N19	1.88	S1N4	54	S12N19	141	S12N19	114
2	S2N19	1.78	S10N23	52	S2N19	133	S2N19	106
3	S1N19	1.70	S12N19	50	S1N19	130	S1N19	106
4	S8N11	1.66	S2N19	49	S8N11	128	S12N21	57
5	S9N13	1.55	S2N23	49	S1N4	122	S1N10	54
6	S7N11	1.54	S9N13	48	S7N11	120	S12N10	48
7	S1N4	1.51	S1N19	47	S9N13	120	S8N11	45
8	S7N13	1.42	S4N4	47	S7N13	112	S4N10	42
9	S3N11	1.32	S7N13	46	S4N4	101	S5N10	42
10	S3N13	1.27	S5N4	46	S5N4	101	S7N11	42

Finally, the intermediation centrality of different nodes and links were analyzed to show that the index or interaction can control the degree of influence. This shapes the ability to control that influence. Table 5 shows the top 10 nodes and links in the betweenness centrality. Emphasizing these evaluation indicators or interactions can significantly reduce the complexity of the index network and improve management performance.

Table 5. Key indicators and links according to the betweenness centrality.

Rank	Index ID	Node Betweenness Centrality	Link ID	Link Betweenness Centrality
1	S1N4	0.050	S2N2→S1N10	40.544
2	S9N13	0.049	S2N2 →S1N20	39.298
3	S2N2	0.048	S2N14 →S6N16	29.483
4	S7N13	0.045	S3N5→S2N2	29.440
5	S5N4	0.032	S6N14 →S1N16	28.163
6	S1N2	0.030	S6N14 →S2N16	27.701
7	S4N4	0.029	S1N16→S2N19	26.931
8	S8N11	0.025	S9N15→S12N21	26.032
9	S7N11	0.024	S2N2→S12N20	25.454
10	S3N13	0.023	S12N15→S4N21	24.738

Table 5 presents the most important connections related to the key indicators. Controlling these key indicators is particularly important. This is because, if the links for these key indicators are cut off, the entire network would be paralyzed. This would prevent the achievement of the project's sustainability goals. These indicators are analyzed next. Key indicators, including S1N4, S9N13, and S2N2, represent waste management, the application of energy saving, ecology, and intelligent technology, and land use. These indicators are particularly critical in this network, and managerial control of these key indicators can significantly enhance management performance. The stakeholder groups associated with these indicators include governments, planning/design enterprises, research institutes, owners, and contractors. This analysis shows that these stakeholders play a key role in the evaluation network of MSCPs. Rational project management will effectively reduce evaluation complexity and improve management performance. Comparing the centrality of nodes with the centrality of links, the research concludes that government departments occupy the main position in the network of sustainable indicators. The link between S2N2 and S1N10 has the greatest degree of centrality. This shows that, of the indicators, land use will have an important impact on market supply and demand.

Government decisions significantly impact owner and investor behaviors. The links to the governments (S1) have the highest centrality, demonstrating the government's important role in the project evaluation network from the opposite side. In the practice of mega sustainable construction, the government can influence the strategic decisions of investors using different incentive policies. The percentage of community residents who must be relocated due to the project and noise level is an important consideration for government departments. In turn, investors are more likely to consider life-cycle costs when the government offers preferential policies. When the cost is within its acceptable range and is more profitable than traditional large-scale construction projects, the owner and investor choose to invest in MSCPs. Different types of construction projects will also affect a region's economic diversity. Therefore, in the network of evaluation indicators for MSCPs, the primary responsibility for researching evaluation indicators lies with scientific research institutions. When implementing the project, this research found that the policies formulated by government departments are most critical in carrying out the evaluation.

5. Discussion

The analysis of indicators for MSCPs, and research on combining stakeholders and indicators using social network methods for these projects remain in their infancy. This study's stakeholder analysis found that the government has the most influence on the actual operation of MSCPs. The government does and should adopt more incentive policies to support these operations. For example, the government provides more subsidies to manufacturers of low-margin green goods, as discussed by Guo et al. [73]. When determining indicators for MSCPs, the most critical stakeholder is the researcher or scientific research institution, which also plays an important role in developing sustainable building practices. This conclusion also verifies that by Tan et al. [74] in another aspect. In this study, planning/design enterprises, contractors, and suppliers are also very important in implementing evaluation indicators. Wang et al. [75] showed that a company's emphasis on social performance creates a good reputation between internal and external stakeholders. This improves financial performance. Therefore, sustainable construction company managers should consider economic performance, social performance, and environmental performance.

In researching the evaluation indicator network, applying energy-saving and intelligent technology in the whole indicator network provides the most connection with other indicators and has the most extensive influence. This further validated the article by Ahn et al. [76], who found that the most important driving factors for sustainable design and construction are energy conservation, improvement of indoor environmental quality, environmental/resource conservation, and waste reduction. The results of the analysis show clear differences between traditional projects and MSCPs. Firstly, user/owner satisfaction, which is related to end-users, owners, and surrounding populations, is more important in MSCPs than traditional projects. Secondly, market supply and demand has the largest range of influence on the MSCPs, but has less influence on traditional projects. Thirdly, key stakeholders such as surrounding populations are regarded as less important for traditional projects than for MSCPs, which implies that MSCPs are more subject to public opinion. The impact of renewable energy utilization efficiency also deserves attention. Wind energy in renewable energy sources results in lower greenhouse gas emissions than other renewable energy sources. This form of energy also demands less water and has a larger social impact, but it requires more land and has higher capital costs [77]. Renewable-energy technologies are mostly realized in developing countries using hydropower technologies. This requires adequate technology, knowledge, and policy support. Constructing energy infrastructure is key to producing renewable energy and ensuring the sustainable achievement goals [78].

Many indicators related to government departments have an important impact on the entire network of indicators. Compared to other stakeholders, government departments pay more attention to economic diversity, market supply and demand, and waste management in the area's projects affect. This may be related to China's rapid urbanization and increased emphasis on environmental protection.

For example, the government is strongly supporting the development of high-tech environmental protection industries. This highlights the importance of dividing the evaluation indicator of MSCPs into the three dimensions of environment, society, and economy. In previous research on sustainability indicators for mega construction projects, Shortall et al. [58] and Farzanehrafat et al. [63] focused on identifying evaluation indicators and determining weights. Shi et al. [79] accounted for stakeholders when analyzing sustainable construction at the project level. This study identified 12 stakeholders and 23 evaluation indicators to study the sustainable development level of mega construction projects. The indicators were divided into social, economic, and environmental dimensions. Stakeholders were linked to the evaluation indicators; a network perspective was applied to determine the strength of the link between the indicators and stakeholders, and the impact of different indicators was determined. Finally, a network visualization model was successfully established. This method can help project participants simplify the steps for identifying key evaluation indicators. This solves the problem of integrating evaluation indicators with mega construction projects, but also promotes a higher efficiency of sustainable project management.

In practice, results in this study may help mega construction project participants reduce the pressure of identifying many stakeholders and evaluating indicators. Firstly, the 12 stakeholders and 23 evaluation indicators in Table 2 can help participants identify their own stakeholders and indicators more clearly. It may also help them better understand the links between these different stakeholders and indicators. Secondly, the SNA model established in this study can help determine the key stakeholders and evaluation indicators based on network theory; the study also presented the potential degrees of interaction. As a result, project participants can focus on the evaluation indicators that significantly impact sustainability levels. Finally, this study established links with stakeholders in the process of identifying key evaluation indicators. This may help project participants identify key stakeholders who have important links to key indicators, improving their ability to manage from a stakeholder perspective, and further improving the sustainability of mega construction projects.

This study also redefined the sustainable construction concept through a list of sustainability indicators. It can be used to evaluate the sustainability performance. These indicators incorporate not only the major international sustainability metrics (economy, environment, and society) [6,19,23,80], but also linked them to stakeholders. The identified key stakeholders can simplify the steps for identifying key evaluation indicators. This study showed that government agencies should develop subsidy policies that apply energy-saving eco-intelligent technologies to the sustainability of mega construction projects. Agencies should also promptly respond to the needs of different stakeholder groups. Project investors should pay attention to government agency involvement and make decisions based on the policies they set. In the process of implementing projects, the interactions between the project, government, and other stakeholder groups (such as subcontractors, financial institutions, and scientific research institutions) will enhance the sustainability of mega construction projects.

6. Conclusions and Recommendations

Using the SNA method and stakeholder management theory, this study linked the evaluation indicators of MSCPs with stakeholders. Using a comprehensive literature analysis and expert interviews, 12 key stakeholder groups were identified for MSCPs. The key stakeholders include government departments, owners/investors, planning/design enterprises, research institutes, and contractors. Government departments play an important role in sustainable construction, and government incentive policies positively impact investments in MSCPs. These findings provide a useful reference for the Chinese government's construction department to take appropriate measures to improve the sustainability level of mega construction projects. For instance, the government can significantly promote the development of sustainable construction by providing policy incentives to investors and financial institutions. In the same way, the study derived 23 indicators to evaluate sustainable construction. The key indicators are the economic diversity of the area affected by the project, the application of energy-saving ecological intelligent technology, waste management, and market supply and demand. This means that the application of economic diversity and energy-saving ecological intelligence technologies in the areas affected by mega construction projects may largely determine the sustainability level. These key indicators may capture the government's attention, and they can formulate targeted policies. Therefore, emphasizing the strong management of these key stakeholders and key indicators may address the complexity of sustainable evaluation and improve management efficiency. According to the key indicators mentioned above, "further market-based incentives for MSCPs", "financial incentives for the application of energy-saving ecological intelligent technology", and "mandatory government policies and regulations for waste management" were the three strategies which can promote construction sustainability.

This study applied a social network analysis method to provide a new perspective on the identification of key stakeholders and key evaluation indicators for MSCPs. This method can help project participants simplify the steps for identifying key evaluation indicators. For example, contractor decision-making is affected by the supply and demand of the market, which largely impacts the development of mega sustainable construction. In addition, study results showed that the application of energy saving, ecology, and intelligent technology, as well as land use and waste management are the most important indicators of sustainable building evaluation, which differed from other studies [35,37]. This is because the evaluation tools used in those studies focused more on the environmental dimension and less on the socio-economic dimension. This led to differences in the results. Comprehensive analysis and evaluation indicators should be considered during data collection to address this problem.

This research did have some limitations. Firstly, the degree of connection between indicators for MSCPs was mainly based on knowledge shared by 36 interviewees; this knowledge was used for assessment. These respondents may have limited expertise in the indicators of MSCPs. Future studies should focus on collecting more comprehensive data that include more potential evaluation indicators. In addition, the stakeholder group sample size would benefit from being larger. This might make the conclusions more stable. However, highlighting these opportunities does not eliminate the contribution of this research. The in-depth interviews with representative stakeholders can determine network trends.

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